APPENDIX F

DETAILED GALVANIC CATHODIC PROTECTION DESIGN EXAMPLE BASED ON LONGVIEW LAKE INTAKE TOWER EMERGENCY DRAWDOWN GATE LEAF

F-1. Design for Drawdown Gate Leafs

Figures F-1 and F-2 show a Longview Lake Emergency Drawdown Gate Leaf. This gate is approximately 2.13 m (7.0 ft) long and 2.29 m (7 ft - 6 in) high. With the lake at normal water level, portions of each gate will always be submerged and other portions may be submerged or exposed as operation changes. During times of high water, more gate surfaces will be submerged, and under conditions of flood, the entire gates may be submerged. Given these variable conditions, the cathodic protection system shall be designed to protect both sides of the gate for its full depth.

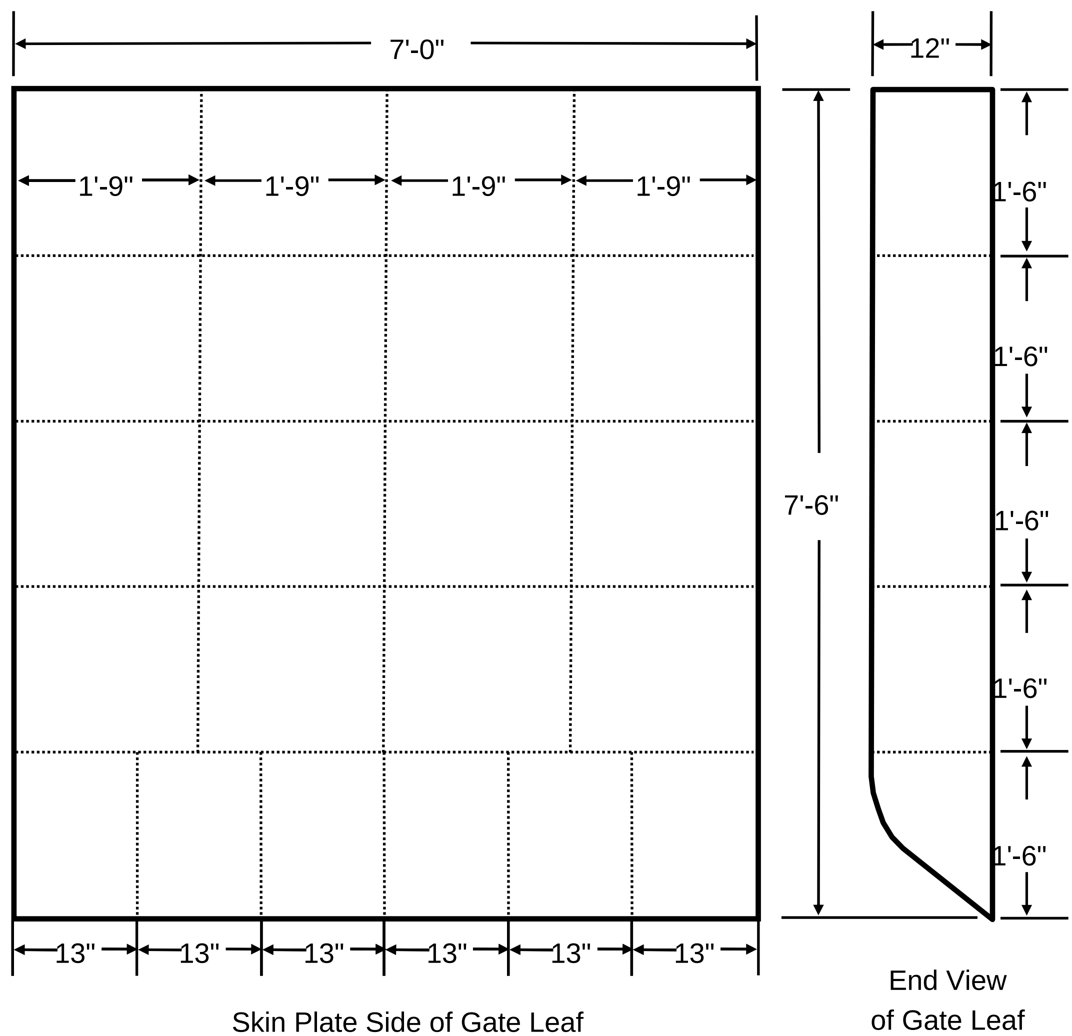

FIGURE F-1. DRAWDOWN GATE LEAF, UPSTREAM STRUCTURAL LAYOUT

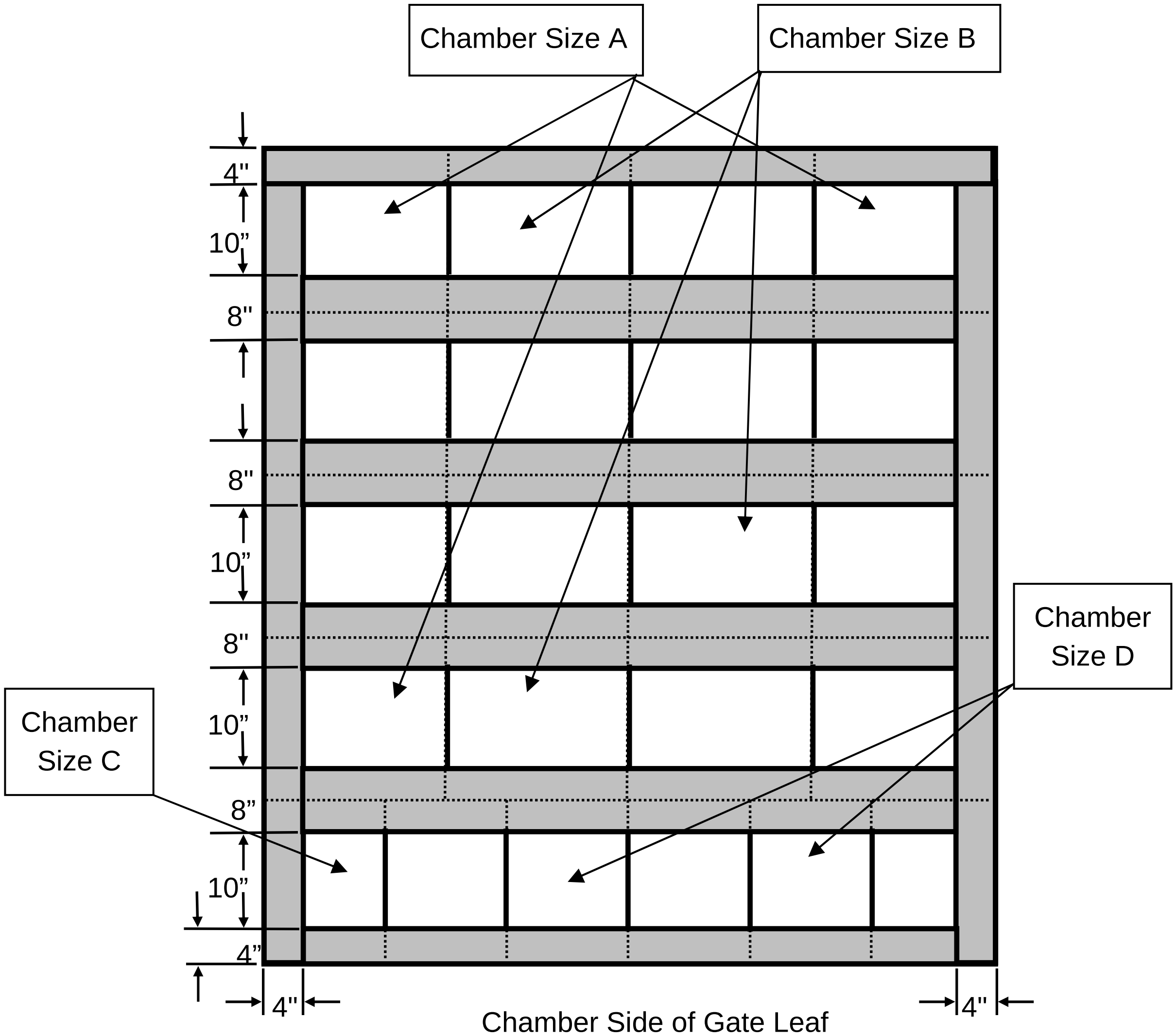

FIGURE F-2. DRAWDOWN GATE LEAF, DOWNSTREAM STRUCTURAL LAYOUT

The leaves are constructed of welded structural steel with both horizontal and vertical framing. The downstream side of the leaf consists of a pattern of rectangular chambers closed on five faces and partially open to the water on the sixth face. The upstream face of the leaf is covered with a single skin plate measuring 213 cm (7 ft) wide by 229 cm (7 ft - 6 in.).

The main (large) chambers (chambers A and B) on the downstream face of the gate are set in four columns and are approximately 53 cm (1 ft - 9 in.) wide by 46 cm (1 ft - 6 in.) high and a depth of 30.5 cm (12 in.). The A chambers are partially faced on the top and bottom and on one side by steel plates that are 10 cm (4 in.) wide, and the B chambers are partially faced only on the top and bottom by steel plates that are also 10 cm (4 in.) wide. The six smaller bottom chambers (chambers C and D) are somewhat smaller — approximately 33 cm (13 in.) wide by 46 cm (1 ft-6 in.) high with a depth of 30.5 cm (12 in.). The two outermost D chambers are partially faced on the top and bottom and on one side by steel plates that are 10 cm (4 in.) wide, and Chamber C is partially faced only on the top and bottom by steel plates that are also 10 cm (4 in.) wide.

F-2. Design Data

The following information *must* be known to design a CP system for this example application or for any other gate leaf structure and environment:

a. The lock is located in fresh water with a resistivity of 1900 ohm-centimeters. Note that this information must be measured either onsite or from sample of water obtained onsite. The sample should be obtained when the water onsite is at it's highest resistivity, which is usually in the fall, when rainfall and run-off are at their lowest for the year).

b. Water velocity is less than 1524 mm/s (5 ft/s).

c. Water contains debris, and icing will occur in the winter.

d. The gate surfaces have a new vinyl paint coating, minimum of 0.15 mm (6 mils) thick, with not more than 1 percent of the area bare due to holidays in the coating.

e. The coating will deteriorate during 20 years of exposure. Based on recent experience with the coating systems presently being applied in the field, it is reasonable to assume that 15 percent of the surface area will become bare in 20 years.

f. Design for 75.35 mA/m2 (7.0 mA/ft2) (moving fresh water).

g. Design for a 20-year life.

h. Design for normally submerged surface areas.

i. For galvanic anode systems, anode specifications must be based on the maximum (final) current requirement over the design life because the current cannot be readjusted over time.

F-3. Computations

a. Find the Surface Area to be Protected

(1) Upstream Side

i. Area of Skin Plate: The gate leaf has an overall height of 2.29 m and is sometimes completely submerged. The width of the gate covered by the skin plate measures 2.13 m. Therefore, the submerged surface area of the skin plate is 2.29 m x 2.13 m = 4.88 m^2 (52.5 ft^2).

(2) Downstream Side

i. Largest-Area Downstream A-Chamber Areas: Eight larger chambers adjacent to the skin plate each have the surface area of a cube on the interior less the open part of the downstream side plus the exterior 10 cm (4 in.) wide surface plate on three sides. The cube surface area is the sum of their six side areas, or [2 x (0.53m x 0.46m + 0.53m x 0.30m + 0.46m x 0.30m) = 2 x 0.541 m^2 = 1.08 m^2] minus the open area of [0.25 x 0.43 = 0.11 m^2] plus the outside surface area of the 10 cm plate perimeter on three side of [0.10 x (0.53 + 0.53m + 0.25) = 0.131 m^2] = 1.08 m^2 – 0.11 m^2 + 0.131 m^2 = 1.10 m^2.

ii. Second-Largest-Area Downstream B-Chamber Areas: Eight larger chambers adjacent to the skin plate each have the surface area of a cube on the interior minus the open part of the downstream side plus the exterior 10 cm (4 in.) wide surface plate on three sides. The cube surface area is the sum of their six side areas [2 x (0.53m x 0.46m + 0.53m x 0.30m + 0.46m x 0.30m) = 2 x 0.541 m^2 = 1.08 m^2] minus the open area of [0.25 x 0.53 = 0.13 m^2] plus the outside surface area of the 10 cm plate perimeter on two sides of [0.10 x (0.53 + 0.53m) = 0.106 m^2] = 1.08 m^2 – 0.13 m^2 + 0.106 m^2 = 1.06 m^2.

iii. Smaller-Area Downstream C-Chamber Areas: Eight of these normally submerged chambers adjacent to the skin plate each have the surface area of a cube on the interior minus the open part of the downstream side plus the exterior 10 cm (4 in.) wide surface plate on three sides. The cube surface area is the sum of their six side areas [2 x (0.33m x 0.46m + 0.33m x 0.30m + 0.46m x 0.30m) = 2 x .39 m^2 = 0.78 m^2] minus the open area of [0.23 x 0.25 = 0.06 m^2] plus the outside surface area of the 10 cm plate perimeter on three side of [0.10 x (0.33 + 0.33m + 0.25) = 0.091 m^2] = 0.78 m^2 – 0.06 m^2 + 0.091 m^2 = 0.81 m^2.

iv. Smallest-Area Downstream D-Chamber Areas: Eight larger normally submerged chambers adjacent to the skin plate each have the surface area of a cube on the interior minus the open part of the downstream side plus the exterior 10 cm (4 in.) wide surface plate on three sides. The cube surface area is the sum of their six side areas [2 x (0.33m x 0.46m + 0.33m x 0.30m + 0.46m x 0.30m) = 2 x .39 m^2 = 0.78 m^2] less the open area of [0.23 x 0.25 = 0.06 m^2] plus the outside surface area of the 10 cm plate perimeter on two side of [0.10 x (0.33 + 0.33m) = 0.066 m^2] = 0.78 m^2 – 0.06 m^2 + 0.066 m^2 = 0.79 m^2.

(3) *Create a Summary Table of Area for Each Chamber*

TABLE F-1. CHAMBER AREA VALUES

				Area Each		Area Total	
Chamber or Surface ID	**Side of Gate**	**Type of Area**	**Total of Each**	**m^2**	**ft^2**	**m^2**	**ft^2**
A	Downstream	Chamber	8	1.1	11.8	8.8	94.7
B	Downstream	Chamber	8	1.06	11.4	8.5	91.5
C	Downstream	Chamber	2	0.81	8.7	1.62	17.4
D	Downstream	Chamber	4	0.79	8.5	3.16	34.0
Skin	Upstream	Chamber	1	4.88	52.5	4.88	52.5
Total Submerged Area						27.0	290.2

b. Calculate the Current Required for a Single Structure Component

$$I = A \times I'(1.0 - C_E) \qquad \text{[EQ 1]}$$

where:

A = surface area to be protected

I' = required current density per bare ft^2 of steel submerged to adequately protect gate = 75.35 mA/m^2 = 7 mA/ft^2

C_E = coating efficiency (0.85 at end of 20 years service)

Skin plate requirement:

$I = 4.88\ m^2 \times 75.35\ mA/m^2 \times (1 - .085) = 55.2\ mA$

c. Create a Table of Current Requirements for Each Structure Component

TABLE F-2. CURRENT REQUIREMENTS FOR EACH STRUCTURE COMPONENT

Chamber or Surface ID	**Side of Gate**	**No. of this Type**	**Area Each m^2**	**Current Density I' (mA/m^2)**	**$1 - C_E$**	**Min. No. Anodes***	**Current Required per Unit (mA)**	**Current Required for All Units (mA)**
A	Downstream	8	1.1	75.35	0.15	1	12.4	99.2
B	Downstream	8	1.06	75.35	0.15	1	12.0	96
C	Downstream	2	0.81	75.35	0.15	1	9.2	18.4
D	Downstream	4	0.79	75.35	0.15	1	8.9	35.6
Skin	Upstream	1	4.88	75.35	0.15	1	55.2	55.2
Total Current Required:								304.4

* To ensure uniform current distribution, it is normally good design practice to provide at least 1 galvanic anode per 10 m^2 structure surface to be protected.

F-4. Anode Design Based on Using Flush-Mounted Slab or Disk Anodes

a. Select Anode Alloy

Refer to Appendix C, Table C-3, for current output data associated with magnesium and zinc alloys. Because the water resistivity is approximately 1900 ohm-cm, and considering both the current output available and required anode life, it is apparent that the preferred alloy anode material is either H-1 Grade A or B magnesium alloy. Should none of the available shapes provide sufficient current, then we would re-evaluate using high-potential magnesium alloy anodes. If anode life would be too short with either magnesium alloy, then consider using high-purity zinc alloy anodes.

b. Select Anode Size

Size is based on current required for each size chamber and the skin plate. Because there are multiple chamber sizes to consider, start with the smallest surface and then sequentially evaluate the larger chambers because designing the smaller components is easier and will help familiarize the designer with the process.

(1) Chamber D

i. Current Required = 8.9 mA

ii. Initial Anode Selection: Refer to Tables C-4 through C-10 and select the chart with the resistivity closest to that of the measured water resistivity. In this case, the water resistivity is 1900 ohm-cm, so consult Table C-6. That table includes a bar chart of the data it presents, and the chart makes it easy to determine which anodes may be appropriate for the D-chambers. From the chart, we could consider the use of the 1x6x12SBE in high-purity zinc (output = 12 ma), a 2x6x12SCE also in high-purity zinc (output = 9 ma), or a 2x5RCE in H-1 alloy magnesium (output = 13 ma).

iii. Anode Selection Based On Life: We want the anode to last 20 years. Figure C-2 indicates that only the 2x5RCE magnesium anode will not have enough life (20 years desired) at 13 ma output. Figure C-3 indicates that both zinc anodes have the required life at their respective outputs of 9 ma and 12 ma. Since the 2x6x12SCE has sufficient life and will provide the desired current for this chamber, we will install one 2x6x12SCE plastisol-coated high-purity zinc alloy anode for the two D-chambers. We also check Table F-2 and note that one anode per chamber is all that is required for good current distribution in these chambers.

(2) Chamber C

i. Current Required = 9.2 mA

ii. Initial Anode Selection: Refer to Tables C-4 through C-10 and select the chart with the resistivity closest to that of the measured water resistivity. Since the water resistivity is 1900 ohm-cm, consult Table C-6. That table includes a bar chart of the data it presents, and the chart makes it easier to discern which anodes may be appropriate for the C-chamber. From the chart, we could consider the use of the 1x6x12SBE in high-purity zinc (output = 12 ma) or a 2x5RCE in H-1 alloy magnesium (output = 13 ma). Because the actual water resistivity is 5% less than the chart value of 2000 ohm-cm, the anodes will put out 5% more current than Table C-6 indicates. Thus we can also consider the use of the 2x6x12SCE in high-purity zinc (output in 1900 ohm-cm = 9.5 ma).

iii. Anode Selection Based On Life: We want the anode to last 20 years. Figure C-2 indicates that only the 2x5RCE magnesium anode will not have enough life (20 years desired) at 13 ma output. Figure C-3 indicates that both zinc anodes have the required life at their respective outputs of 9.5 ma and 12 ma. Because the 2x6x12SCE has sufficient life and will provide the desired current for this chamber, we will install one 2x6x12SCE plastisol-coated high-purity zinc alloy anode for the four C-chambers. Again, we also check Table F-2 and note that one anode per chamber is all that is required for good current distribution in these chambers.

(3) Chamber B

i. Current Required = 12 mA

ii. Initial Anode Selection: Refer to Tables C-4 through C-10 and select the chart with the resistivity closest to that of the measured water resistivity. Since the water resistivity is 1900 ohm-cm, consult Table C-6. That table includes a bar chart of the data it presents, and the chart makes it easier to discern which anodes may be appropriate for the B-chambers. We will not consider the 5 in. round magnesium anode since we already know its life will not be sufficient. Thus, from the chart, we see that the only anode we should consider in magnesium is the 1x6x12SCE in H-1 alloy (output = 23 ma) or the 2x6x12SBE in zinc alloy (output also = 12 ma).

iii. Anode Selection Based On Life: We want the anode to last 20 years. Figure C-2 indicates that the 1x6x12SCE in H-1 alloy magnesium will not have enough life (20 years desired) at 23 ma output. Figure C-3 indicates that the 2x6x12SBE in zinc alloy (output also = 12 ma) will have the required life. Because the 2x6x12SCE has sufficient life and will provide the desired current for this chamber, we will install one 2x6x12SBE plastisol-coated high-purity zinc alloy anode for the eight B-chambers. Also, since we are using zinc with a maximum driving potential of 1100 mV versus a Cu-$CuSO_4$ reference electrode, we do not have to worry about cathodic debonding of the coating adjacent to the anode. Therefore, no additional dielectric shielding is needed behind the anode other than the plastisol coating that will be left in place on the back side of the anodes and on the core extensions (except around the mounting bolts where the plastisol must be removed to provide electrical contact between the bolt, core, anode, and lift gate). Again, we also check Table F-2 and note that one anode per chamber is all that is required for good current distribution in these chambers.

(4) Chamber A

i. Current Required = 12.4 mA

ii. Initial Anode Selection: Refer to Tables C-4 through C-10 and select the chart with the resistivity closest to that of the measured water resistivity. Again, the water resistivity is 1900 ohm-cm, so consult Table C-6. That table includes a bar chart of the data it presents, and the chart makes it easier to discern which anodes may be appropriate for the A-chambers. We will not consider the 5 in. round magnesium anode since we already know its life will not be sufficient. Thus, Table C-6 indicates that the only anode we should consider in magnesium is the 2x6x12SBE in zinc alloy (output = 12.6 ma in 1900 ohm-cm water = 5% greater than the chart value of 12 ma in 2000 ohm-cm water).

iii. Anode Selection Based On Life: We want the anode to last 20 years. Figure C-2 indicates that the 1x6x12SCE in H-1 alloy magnesium anode will not have enough life (20 years desired) at 23 ma output. Figure C-3 indicates that the 2x6x12SBE in zinc alloy (output also = 12 ma) will have the required life. Since the 2x6x12SCE has sufficient life and will provide the desired current for this chamber, we will install one 2x6x12SBE plastisol-coated high-purity zinc alloy anode for the eight A-chambers. Again, since we are using zinc with a maximum driving potential of 1100 mV versus a Cu-$CuSO_4$ reference electrode, we do not have to worry about cathodic debonding of the coating adjacent to the anode. Therefore, no additional dielectric shielding is needed behind the anode other than the plastisol coating that will be left in place on the back side of the anodes and on the core extensions (except around the mounting bolts where the plastisol must be removed to provide electrical contact between the bolt, core, anode and lift gate). Note we also check Table F-2 to see that one anode per chamber is all that is required for good current distribution in these chambers.

(5) Skin Plate

i. Current Required = 55.2 mA

ii. Initial Anode Selection: Refer to Tables C-4 through C-10 and select the chart with the resistivity closest to that of the measured water resistivity. Since the water resistivity is 1900 ohm-cm, consult Table C-6. That table includes a bar chart of the data it presents, and the chart makes it easier to discern which anodes may be appropriate for the skin plate. We note that the only single H-1 alloy anode with sufficient capacity to protect the entire skin plate of the gate leaf is the 4x9x18SBE anode. However, this bare-edge magnesium anode would require the use of a supplementary dielectric shield as discussed in the next paragraph. Because such use is not recommended, we will consider the use of two anodes instead with each having an output of at least 28ma. The 2x8x8SCE high-potential magnesium alloy anode (30 ma output), the 2x6x12SCE high-potential magnesium alloy anode (32 ma output), and the 2x9x18SCE H-1 alloy magnesium anode (37) could be used. Any one of these three anodes could be used based on their current output.

iii. Use of Plastisol Coatings: Plastisol restricts the current flow to the anode face, but after the coating is cut away from the face it improves current distribution (for magnesium anodes only on coated structure and for both zinc and magnesium on bare structures) because current from the sides of the anode cannot flow to the steel immediately adjacent to the anode. With bare-edge magnesium anodes, it is necessary to place a neoprene rubber shield behind the anode which is extended beyond the anode perimeter at least 2 in. This shield must be glued in place, typically using 100% silicon caulk. Unfortunately, this shielding material can be damaged by the ice and debris floating down the river and impacting primarily on the exposed skin plate anodes. Thus, it is normally recommended that the skin plate anodes be entirely coated with plastisol, with a window cut from the coating on the anode face to expose the operating surface. Therefore, we will not consider the use of bare-edge magnesium anodes for any upstream gate or leaf surface. Bare-edge zinc anodes may be used on coated skin plates since the coating will function as the dielectric shield without being damaged by the anode current output over the system design life.

iv. Anode Selection Based On Life: We want the anode to last 20 years. Using Figure C-2, we see that the 2x8x8 anode will only last about 15 years at 30 ma and therefore is not suitable for this project. The 2x6x12 also falls slightly short of the desired life at 32 ma output. Only the 2x9x18SCE H-1 alloy anode will work, providing over 30 years life at 37 ma current output. Thus, we will install two 2x9x18SCE H-1 magnesium alloy anodes with plastisol-coated back and sides to protect the skin plate. It should be noted that the use of two anodes exceeds the minimum number of one anode required for good current distribution, as shown in Table F-2.

c. <u>Develop Anode Locations for Each Structure Element</u>

Locating anodes is simply a geometric process of distributing the anodes uniformly on each structure element to achieve good current distribution.

(1) <u>Chambers A, B, C, and D</u>

In this example, locating of the anodes in the chamber with one anode only is simple in that the anode will be located in the center both vertically and horizontally on the back surface of the each chamber to receive a single anode.

(2) <u>Skin Plate</u>

Since the skin plate will usually require two anodes that will be distributed uniformly both vertically and horizontally , the design procedure is somewhat simpler than that for the larger structures designed earlier in this document. Geometrically, the two anodes can either be distributed vertically along the vertical bisector of the leaf or horizontally along the horizontal bisector. Since the leaf is taller than it is wide, we choose the former vertical layout. The topmost anode is simply located one-quarter the way down from the top of the leaf (2.29 m x

0.25 = 0.57 m) and the bottom anode is located one-quarter the way up from the bottom of the leaf (also 0.57 m).

The layout for these anodes on the skin plate is shown below in Figure F-3.

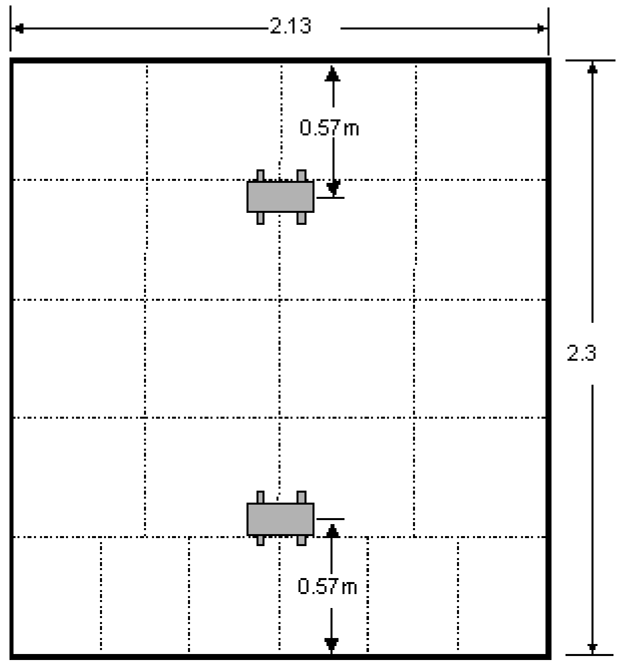

FIGURE F-3. ANODE CONFIGURATION ON
UPSTREAM SKIN PLATE SIDE OF GATE.